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# The Nature of Cosmic Rays

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THE NATURE OF COSMIC RAYS

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During the last 2 or 3 years, two organizations of young physicists under the direction of Professor S. N. Vernov and Doctor of physico-mathematical sciences N. A. Dobrotin have extensively investigated the general problem of cosmic rays by various methods and in various laboratories.

These numerous investigations (counted in the tens), to which the present synoptic report is devoted, were carried out in the main Physical Institute, imeni P. N. Lebedev Academy of Sciences USSR, in participation with Moscow University and Academy of Sciences Uzbek SSR.

Besides the above-mentioned directors, I should like to mention also corresponding-member Academy of Sciences USSR V. I. Veksler, who contributed to the works of the Physical Institute group in the initial stages.

This collective work owes its support to the party and government.

Cosmic rays, which consist of particles that have accumulated somewhere in the depths of the universe immense energies unusual under our terrestrial conditions, for more than 40 years have been attracting the attention of numerous investigators, who are concentrating ever greater efforts on this advanced front of nuclear physics.

However, despite the published achievements and numerous discoveries enriching our knowledge with new facts and new representation of unusual significance, until



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very recently we did not have any precise picture or even a basic scheme to explain the phenomena of cosmic rays. Moreover, even the question about the very nature of primary cosmic rays remained until recently open for discussion.

It is not difficult to point out the reason for such a position of things. The phenomena which arise from cosmic rays in the atmosphere are extremely complicated. As they penetrate into the depths of the atmosphere, the cosmic rays are subjected to many successive transformations. Even in the lower layers of the atmosphere, the observer is concerned mainly, not with primary particles, but with the particles generated by them not in the first but in some very distant generation.

Until most recently, the main efforts were in investigating cosmic rays in the lower layers of the atmosphere, since the stratosphere remained heretofore little accessible for experimentation. It is not surprising that attempts to construct a general concept of cosmic rays phenomena did not lead to satisfactory results.

Such a construction lacked a firm foundation, since the first link in the chain of transformations, undergone by cosmic rays in the atmosphere, remained undiscovered.

At present, as the result of works about which we shall speak further on, we have already completed a hopeful basis for establishing the basic scheme of these transformations. These works finally obtained data that permit us at last to solve the problem of the nature of primary rays. And what is particulary important, we can even now construct a general picture of those phenomena which are caused in the stratosphere by the primary cosmic particles, which ensures us a hopeful position for the future discovery of the mechanism governing the transformation of cosmic rays in the atmosphere in all their complexity.

In order to make understandable the many ideas at the basis of the indicated works, I will linger on those hypotheses which have been shown unfit, which now repose in historical archives, but which for a rather long time had known general recognition.

One such hypothesis, suggesting a very firm basis, was the hypothesis of the electrical nature of primary cosmic rays.

The assumption that the primary particles of cosmic rays are electrons arose from the necessity to explain how the high energy of the cosmic ray particles can be associated with their relatively great absorption in the atmosphere.

Thefact is, successful measurement of the energies of primary cosmic particles (statements below will give some idea how this was accomplished) immediately revealed that the absorption of these particles in the atmosphere cannot be reduced to simple retardation in which charged particles moving in a gas or in some other medium cause its ionization by tearing the electrons from those atoms with which they collide in their path and thus expending a definite amount of energy. For not very high energies, the retardation of a charged particle completely determines the energy expended in ionization. Such "ionizational" retardation can be accurately computed.

Thus, if one takes into account the energy of the primary particles and calculates what proportion of the energy these particles would disperse during passage through the earth's atmosphere, if subjected to only one ionization retardation, it turns out that most of the particles could freely penetrate the entire thickness of the atmosphere; but in reality only a small part of all particles present in the stratosphere ever reaches the earth's surface.

Another absorption mechanism is known, however, which leads to a much more rapid scattering of energy. This mechanism, acting only for very great energies of the particles, is characteristic for such "light-weight" particles as the electrons. By virtue of the capacity of rapidly moving electron to radiate its energy during collision with atoms of the retarding medium, the "radiational retardation" [Brehmsstrahlung] connected with this capacity will dominate, for great velocities, ionizational retardation.

The intervention of new mechanisms in the phenomenon of retardation for large energies of the particle, however, is still not limited to this. If only one radiational mechanism of absorption were operating, then the fast electron moving in the medium would very soon "overgrow" with a cluster of particles accompanying it, identical in nature with atoms of light - namely, with a cluster of high-energy photons - and its energy would very rapidly transform into the energy of electromagnetic radiation. But high-energy photons also prove to be highly capable of absorption. During their absorption they produce "pairs" of particles, consisting of one negative and one positive electron. Successive repetition of the production of photons by electrons and, conversely, of electrons by photons accompanying the motion of the primary electron leads to the formation, as a result of repetition, of many cascades (co-called "cascade multiplication") of powerful showers of particles, if the primary energy is very great, or even one "shower" consisting of several or several tens of particles, in the case of less energy.

The generation of a shower is generally characteristic of cosmic rays. As we shall see, besides the electromagnetic mechanism for explaining the generation of rays just described, which can be called classical, we also encounter in cosmic rays other showers of another nature and derivation.



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On the basis of the cascade theory, apparently, it was possible to clarify completely the behavior of the curve describing the absorption of the predominant soft-component in the atmosphere, if the primary cosmic rays are assumed to be a flux of high-energy electrons. Such an electron, falling into the stratosphere from space, should cause an intensive cascade process. By virtue of cascade multiplication the primary high-energy electron generates many other electrons of less energy. For this reason, if a flux of such electrons should come into the earth's atmosphere from space, then the number of particles and concomitant ionization should initially increase as they advance downwards into the depths of the atmosphere, which should create the characteristic so-called "transitional" maximum. Further on, however, the energy of the generating shower rapidly diminishes and dissipates in ionization, caused already not by one but by many particles composing this shower.

The energy of primary rays is known. Utilizing the shower, or cascade, theory one can calculate the absorption curve just described and convince oneself of the quantitative agreement, not bad for now, of the behavior of the curve thus calculated with the absorption curve as obtained from observed data, which shows how the energy of cosmic rays is expended and how the flux of particles weakens, and, consequently, also the intensity variation of this radiation with penetration into the atmosphere.

The curve which gives the behavior of absorption of cosmic rays below sea-level has an entirely different form. It has been established from it that we are not concerned with electrons, but with mesons - namely, particles first discovered in cosmic rays and having a mass of a magnitude intermediate between an electron and proton. Such particles - namely, mesons - are not subject to cascade multiplication, and the curve describing the absorption of the corresponding - namely, penetrating or hard - component is very sloping.

After all these preliminary remarks it is possible to sketch the general outline of the problem on the nature of cosmic rays at that stage proceding the work which is the object of my report.

In the course of a rather long time, the following scheme for this chain of transformations undergone by cosmic rays in the atmosphere, about which I spoke in the beginning, came to be generally accepted: primary electron $\longrightarrow$ cascade electrons and photons $\longrightarrow$ mesons. The theory is based, it is true, on more or less arbitrary hypothesis which allow one to predict the production of mesons through absorption of photons.

Approximately 10 years ago doubts arose, however, as to the correctness of this scheme, and an opposite assumption was made, that the flux of primary particles consists of positively-charged elementary nuclear particles - namely, protons. These doubts and this hypothesis were based in part on simple experimental data. Thus, M. Schein* ~~/Note: Russian (phonetic) spelling, which is pronounced "shine" (English word). It is possibly for the Germanic name "Schein"./~~ in America carried out a series of observations in the stratosphere and found that his results contradicted the assumption about the electron nature of primary rays and the above-indicated scheme. He proposed the following scheme: primary protons $\longrightarrow$ mesons electrons.

Schein's experiments were not faultless and his results appeared unconvincing to many. Moreover, the scheme proposed by him led to difficulties of which we state two of the most important ones.

Experiments are possible which allow one immediately to determine the energy and charge (sign) of the particles composing the primary component. The point is, primary cosmic particles, if they possess a charge, in approaching the earth meet

*[Note: Marcel Schein ?]

in their path a definite barrier in the form of the earth's magnetic field. Only those particles which have a certain definite very high energy can reach the earth's surface at any point. If this blocking action of the magnetic pole is compared to some barrier (it is a question of electrical barrier) then it turns out that the altitude of this barrier for points of the earth's surface at various latitudes is not the same. The investigation of the intensity of cosmic rays at various latitudes also permits one, on the basis of the theory of this so-called "geomagnetic" effect, to evaluate the energy of primary particles and, moreover, to establish the energy distribution of these particles.

Determination of the sign of the charge proves to be possible by virtue of the fact that, in equatorial latitudes, west and east directions turned out to be not equally accessible for most primary cosmic ray particles. If cosmic ray particles are charged positively, then in the stratosphere near the equator they will penetrate principally from the west; and, conversely, they came from the east if their charge is negative.

In the year 1939 the well known American specialist Johnson made difficult observations in the stratosphere to search for the above-described effect of so-called "azimuthal asymmetry", but did not discover it. (In every case, according to Johnson's data, this effect did not exceed a tenth of the magnitude possible to expect). Johnson's results, remaining unrefuted and, so to say, unique in the course of 10 years, were in direct contradiction to Schein's hypothesis about the proton nature of primary radiation.

A second difficulty of Schein's hypothesis and of the indicated scheme was that the mechanism explaining the production of electrons, observed in great quantities even at the highest layers of the atmosphere, was unknown. Completely unexplained was the question of what causes this so-called soft component, predominant in the upper layers of the atmosphere and consisting of electrons and accompanying photons. Schein himself proposed that one explanation could be the decay of mesons, one of whose products is electrons. However, more thorough investigation of the problem showed with ~~showed~~ complete clarity the inappropriateness of such an explanation for the generation of the soft component in connection with the relative slowness of the decay process of rapidly moving mesons.

For the explanation of all those questions, 2-3 years ago Professor S. N. Vernov began to investigate cosmic rays in the stratosphere on a large scale and along a wide front.

The results of these successfully conducted investigations finally solved the problem concerning the nature of primary radiation.

Stratospheric investigations, which we are now talking about, are based on the application of a method of observation of cosmic rays that involves the transmission of radio signals; this method has been perfected now to a high degree by great technological skill.

S. N. Vernov, beginning his investigations almost 20 years ago, invented this method of observation of cosmic rays, which has recently begun to be widely utilized also in America.

I shall begin with the simplest experiment, whose results early exclude completely and unequivocally the hypothesis about the electron nature of primary radiation. It is based on the observation of the effect caused by cascade multiplication of electrons.

What is involved is cascade multiplication, which will take place during the passage of high-energy electrons through lead layers. The problem is this: to subject an apparatus which can detect such an effect to the action of primary particles, for the purpose of which it was necessary to carry out experiments at very great altitudes.

In application to the given problem, it was necessary to fulfill the requirement that high-energy electrons, if they arrive from space, have not succeeded in undergoing cascade multiplication in the layer of the stratosphere lying at a higher level, to which the given apparatus has been lifted. This condition was fulfilled, inasmuch as the observations were conducted at heights of 25-27 km above sea-level. The apparatuses are lifted to such altitudes by means of sounding balloons. Cosmic ray particles were recorded by means of a miniature Geiger-Muller counter, in which the incidence of every particle is recorded because of the momentary action of an electric charge which is then quickly extinguished. The ionization pulse caused by such a discharger is transmitted through a radio-transmitter as a suitable radio signal to Earth, where it is also recorded on a moving photographic film through receiver which allows calculation of the particles that have passed in a definite time through the stratospheric counter.

In the experiment under consideration, the counter was shifted by means of a special automatic mechanism controlled by the counter itself, and was alternately inserted into the interior of a hollow lead sphere and then,after a definite number of pulses were counted, withdrawn out of the sphere, thus effecting in a certain interval of time an enumeration of those particles that were not filtered through the lead, and so forth.

The electrons in passing through the lead are subjected to cascade multiplication, thus creating that transitional maximum in the absorption curve, about which I have already spoken. If the rays incident on the apparatus contain electrons, then the number of counts per unit time in the counter located in the interior of the lead sphere proves to be several times greater than that observed in the counter when located outside this sphere. Utilizing the effect of multiplication in lead, it turned out to be possible to work out a method for analyzing the electron component, which method permits one to judge according to the magnitude of the effect the energy of the particles composing this component. I merely touch in passing the large number of works which were completed with the application of not only this, but also two other methods for solving this problem. All these investigations established that great quantities of electrons exist in the stratosphere. Their energies, however, proved to be about 10 times less than the minimum energy which primary cosmic electrons should have in order to overcome the blocking action of the Earth's magnetic field and reach the Earth's surface.

The electrons observed could not have come from space. They, consequently, must have originated already in the Earth's atmosphere itself, but no primary electrons were discovered. The results of the experiments described, however, by no means contradict the assumption that high-energy propons might form the primary component.

The hypothesis about protons and particles, composing primary cosmic rays, still contradict Johnson's experiments, to which I have already made reference. An equatorial expedition was organized to clarify the problem and to obtain new data on particles of energies greater than those in our latitudes (even in the stratosphere). Sounding balloons carrying apparatus were released from the deck of a Soviet ship in the ocean near the equator.

In the case under consideration much more complicated experiments were also carried out by a group under S. N. Vernov's direction (N. L. Grigorov, S. P. Sokolov and others) and the organizational direction of N. A. Dobrotin.

Cosmic ray particles were recorded in the case under consideration (also, of course, through transmission of radio signals back to the earth) by means of coincidence of particles in counters that form a system provisionally called a telescope, because it registers radiation in a definite direction.



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In Figure 1 is shown schematically a series of cylindrical counters forming this telescope, whose axis is set at an angle of 60° with the direction of the zenith. This angle remains constant, but the azimuth changes by 180° in definite time intervals. The axis of the telescope is directed alternately to the west and then to the east. These transitions are made automatically and quickly; as in other cases, the counting apparatus itself regulates the length of time that the apparatus is located in each of the two given orientations. The transitions from one position to another are effected after a definite number of counts obtained in any given definite position.

As the axis of the telescope which, independently of the rotation of the apparatus due to its flight, should always be directed to the east or west; therefore it is equipped (and strictly maintained constant) with a system of photocells which is directed ("controlled") by the sun's rays, which [I.e. Sun's rays] also serve as an orienter for the entire system.

In Figure 1 are seen the results of observations. The curves show the intensity of cosmic rays in functional dependence on height for the two cases of west and east azimuths. The intensity of radiation arriving from the west proved to be greater than the intensity observed in the eastern azimuth, surpassing this latter by 60% of the average quantity corresponding to it, which is also given by calculations for radiation consisting of positive particles. It is established, therefore, that primary cosmic-ray particles are charged positively. The work of Johnson, discussed so much, proved to be inaccurate.

Thus the work described above, which should naturally be considered a great event in our science, finally and with utmost reliability solves the problem concerning the nature of primary radiation, which must be admitted to be a carrier of



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high-energy protons. There is no room for other assumptions, if only one does not admit any hypothesis concerning some new conditions of the particles unobserable on the earth, for which there are no reasons. It is true that the thesis concerning the nature of the primary component should be formulated in a more general form: namely, as an assertion that the energy carriers of primary radiation generated in the depths of space are positively-charged nuclei of atoms, with an overwhelming preponderance of the simplest nuclei - nuclei of the most wide spread atoms - hydrogen; that is protons. As is known now by the photographic-plate method (in the light-sensitive layer of which it is possible to discover the traces of nuclear particles) even more complicated multiply-charged nuclear particles have already been repeatedly observed at great altitudes in the strosphere. Thus, for example, Figure 2 is a microphotograph of the trace of a particle - perhaps, of the nucleus of an oxygen atom obtained as the result of photographic observations in the stratosphere carried out by G. M. Belovitskiy and others in the Physical Institute, Academy of Sciences USSR, in the laboratory of I. M. Frank, corresponding member of Academy of Sciences USSR.

But if the problem of what particles are generated in space and what energy they attain in the upper atmosphere can be considered as solved, then still more acute is the problem concerning the existence of those processes which are caused by these particles when still in the upper layers of the stratosphere and which account for their very intensive absorption.

As a result of all the works described by me, which allowed us to carry out, so to speak, concentric attacks in many directions on this front of science, we now have the solution to the problem just stated.

We abandon the stratosphere for the time being and descent to lower altitudes, in order to become acquainted with the results of extensive investigations undertaken by expeditions into high-mountain regions.

Regrettably, the limited size of my report does not allow me room for these no less noteworthy works remarkable for their size.scale and experimental techniques. which they deserve by their magnitude and significance. I should in general emphasize that my discussion can not be exhaustive. Also, I must again digress from the basic line of discussion for some short, clarifying remarks.

I have already referred to cascade electron showers and to the cascade theory of these showers. To understand the sequence it is necessary to keep in mind the following.

In such cascade showers we are concerned with processes started by the collision of fast electrons and also of photons with the nuclei of atoms composing the medium in which they move. Here, however, we are talking about processes that take place at some distance from the atomic nuclei and are caused by electromagnet forces, whose nature is well known to us.

The investigation of these classical cascade phenomena is extraordinary interest. But inasmuch as the atomic nuclei plays only a passive role in these phenomena , their investigation does not open any new way for approaching the problem of the atomic nucleus, and in particular for solving the problem of the nature of nuclear forces.

Particles of very high energies, however, as a calculations show, collide repeatedly against the atomic nuclei themselves and penetrate them. Such particles can serve as ballonns, as it were, for investigating internuclear interactions and phenomena due to them. Fast electrons, judging from all the data available, prove to be nuclear-passive; that is, particles that do not interact with nuclear matter. For this reason they are unsuitable as "balloons".

It is possible, however, to assume a priori that such high-energy particles as the particles composing the nucleus of matter itself, i.e. protons and neutrons (often designated by the single name "nucleon"), can prove effective instruments for bombarding the atomic nuclei to study the powerful nuclear forces still uninvestigated by us.

During the mountain expedition of 1945-1946, V. I. Veksler, G. B. Zhdanov, A. L. Lyubimov and others made a very important discovery.

Their observations showed that unusual showers of a completely different nature (which we shall provisionally call "special showers"), besides ordinary cascade showers also play an important role in the phenomena of cosmic rays at high altitudes. The distinguishing trait of these "special" showers is that they contain particles able to penetrate great thicknesses of lead: layers of lead several centimeters thick prove to be perfectly transparent for such particles. Filtration, moreover, through relatively thick lead, of the radiation generating these showers does not essentially tell the intensity of their generation. Relative to ordinary cascade showers the opposite is immediately observable: shower-formation is shortened or depressed if the radiation is filtered through 10-20 cm of lead, and the particles themselves composing the cascade showers are practically completely absorbed by lead layers several centimeters thick.

As a result of detailed and diversified investigations into this new phenomenon, carried out under the general direction of N. A. Dobrotin and with the collective efforts of a large group of workers who created new very powerful and complicated tools for investigating these phenomena, it has been recently established that the "special" showers arise as the result of a nuclear process possessing an "explosive" character. Such a nuclear explosion is accompanied not only by the disintegration of the affected nucleus colliding with the "cosmic missile" (and with the complete disintegration of the latter into its component parts), but also by the birth of many new particles as the result of such a catastrophic process.

From the entire data accumulated about which I shall speak later, it follows with a high degree of probability that such a process and such "special showers arise as a result of the action, on atomic nuclei, of either or the primary cosmic-ray particles themselves directly or other nuclear particles created by cosmic rays already in the earth's atmosphere (particularly neutrons), thus obtaining, however, sufficiently high energies of the order of magnitude of the energy of primary particles.

I will now describe, although entirely sketchily, the technics that made it possible to carry out the basic and diversified investigations of all these phenomena.

In describing S. N. Vernov's experiments in the stratosphere, I referred to corpuscular telescopes, consisting of two or three Geiger-Muller counters and permitting one to record cosmic particles passing through during a definite time in some more or less exactly assigned direction. Simultaneous coincident pulses in such a system of several counters making up the telescope signal the passage of particles in a given direction. To investigate the "special" showers, much more complicated systems called hodoscopes made up of scores of counters have been created. Signals arising from the appearance of coincident pulses in some comparatively simple suitably-chosen system composed of several counters serve in a given case for the purpose of "regulation" by the hodoscope. If this signal created by some shower is obtained, then the apparatus makes it possible to discover what has occurred (simultaneously with the phenomenon caused by the given signal) individually in each of the counters making up the hodoscope; that is, the apparatus permits one to recognize - indedd, even directly to see - in which of the counters a discharge took place in consequence of the passage of one or perhaps several particles through it. It is possible to see this directly with the eye because each counter is connected with a small neon lamps that lights up when a discharge, due to particles incident on the counter, has occurred in a given counter.

The system of lamps, fastened on separate panels so that the disposition of lamps likens somewhat the distribution of counters, is photographed every time that a signal is received from the regulating system.

Figure 3 and 4 are photographs of panels with flashing neon lamps. The first of these diagrams shows the passage of individual particles, leaving a trace in the form of a chain of flash lamps placed along a straight line; the second diagram shows the result of the passage of a shower consisting of many particles.

Besides the hodoscopic method, another method, still more effective in the sense of the possibility of direct observation of the entire picture of the phenomenon, was also employed - namely, the so-called controlled "Wilson chamber" method.

In this case, pulses from the regulating system of counters bring into action the Wilson cloud chamber. Inside the chamber, alternate plates of lead and graphite are placed in the path of the particles of the shower investigated. The tracks (covered with fog droplets) passing through the cloud chamber can be photographed directly. Figures 5 and 6 show photographs of showers obtained in such a manner, from the works of N. G. Birger, S. A. Azimov and others. All these showers, which are generated in lead blocks surrounding the chamber and which consist in some cases of an aggregate of particles which fill the entire volume of the chamber in a dense flux are "special" showers.

The apparatus is actually surrounded on all sides by a massive lead shield which completely frees the shower of the electrons that have come from without; and, on the other hand, a considerable portion of the showers photographed in these prints consist themselves of penetrating particles freely able, even without causing cascade multiplication, to pass through considerable thicknesses of lead many centimeters thick, as Figure 5 shows especially clearly.

In these several photographs I could note many interesting peculiarities, already sufficient to explain those conclusions concerning the composition and nature of special showers, which were, however, made on the basis of very much broader material obtained by employing various methods and thorough investigations of the phenomenon as the result of numerous complicated experiments.

I will limit my exposition to only the most important of these conclusions.

Particles discovered in the composition of "special" showers can be divided into three groups. The strongly ionizing and comparatively slow particles form the first group - products of the disintegration of atomic nuclei, in which (i.e. nuclei) the "special" shower arises. These particles are nucleons, obtaining comparatively small energy and representing nothing else than the component parts of the atomic nucleus which are flying apart in various directions, the atomic nucleus having disintegrated in consequence of the explosive nuclear process occurring in its interior. Here we have to do rather with a secondary product of the explosive shower; and the picture successfully observed in this part is probably identical with the picture repeatedly observed even earlier in the photo-sensitive layer of special photographic plates [photographic emulsions]. Figure 7 shows an example of a picture of such a star-shaped splitting, which occurred in a photographic emulsion and subsequently developed; this plate is taken from the collection of the Physical Institute, Academy of Sciences USSR. It is possible to say that here a purely "nuclear" shower is present in the sense that it consists of nuclear particles; namely, individual nucleons and in some cases even alpha-particles.

A great part of the energy of "special" showers is concentrated, however, in two other components, which are of the greatest interest. Such components -- second and third -- prove to be, on the one hand, high-energy electrons and, on the other hand, penetrating particles.

The unexpected discovery of electrons in the make-up of "special" showers is of exceptional theoretical significance. The presence of this electron component means that here we have encountered some essentially new mechanism, to all intents and purposes not subjected heretofore to theoretical investigations. Taking into account this double nature of "special" showers, hereafter we also shall call them electron-nuclear showers.

Of no less real interest is the second result of careful investigation of electron-nuclear showers: It was established that the penetrating component of these showers contains "nuclear-active particles"; that is, particles that themselves can cause new electron-nuclear showers. The existence of these particles in the showers leads to possibly a new cascade process of very large energies perfectly different in nature from that which I have already mentioned more than once; namely, the nuclear-cascade processes in which particles appearing as the result of nuclear explosions create new explosions accompanied by an electron-nuclear shower, and so on.

The problem concerning the nature of the particles composing electron-nuclear showers appears to be the object of further investigations. As for nuclear-active particles, it is natural to assume that these same protons and neutrons could act like this if they were to receive very great energies as the result of an explosive process. Besides nucleons, "heavy" mesons of great energies also possess such an ability to cause nuclear processes; i.e. nuclear activity.

It is possible to consider also as established the fact that the penetrating component of electron-nuclear showers also contain, in considerable numbers, ordinary "non-active" mesons (non-active in the nuclear sense). At present there are already straightforward proofs that these latter particles exist in "special showers.

The fact that electrons of rather high energies are generated in explosive showers possesses prime significance for the explanation of the whole complex of cosmic ray phenomena. I have already mentioned that the assumption concerning the proton nature of primary rays proved to be little acceptable in connection with the fact that it was diffucult to understand how the primary protons can create the high-energy electrons that are observed in great quantity in the highest layers of the atmosphere. As we know, this difficulty arose because this mechanism of the formation of the electron component which is now observed in electron-nuclear showers was not known and, naturally, was not taken into consideration. The discoveries mentioned by me permit stating the thesis that the main electron components and also meson components observed in the atmosphere are born in the stratosphere in the composition of electron-nuclear showers. We shall return to the development of this thesis.

For the present I should like to linger on only one consequence of the statement just made, which leads to the possibility of observing electron-nuclear showers of extraordinary high energies and under conditions such that are concerned with phenomena already on a completely different, much more enormous scale. We are talking about those shower-giants which were discovered 15 years ago by the French physicist Auger. These showers, consisting of hundreds of thousands or millions or even tens of millions of particles, develop through out the entire depth of the atmosphere. The space of laboratory accommodations proves already insufficient to investigate them and observations have to be transferred to the field.

Until recently, it was assumed that showers of such a nature covering areas of the order of a square kilometer in some cases and even larger are created by classical cascade multiplication, when cosmic electrons of extraordinarily high-energies penetrate into the atmosphere.

Taking into account the discoveries about which I spoke, it is necessary, however, to assume that actually atmospheric showers are concerned with large-scale composite electron-nuclear showers created in the stratosphere by primary protons of very high energy. From this point of view the study of atmospheric showers becomes of new practical interest. The presence, established by previous observations (and accurately investigated in many works under mountainous conditions), of the penetrating meson component of these showers becomes immediately understandable. The works to which I now refer, which give extremely valuable new results, were carried out under the immediate supervision of our young, but already very competent, specialist G. T. Zatsepin, who also proposed a new concept of the nuclear-cascade process lying at the basis of this phenomenon. I am unable to allot to these works sufficient room in my report.

Up to now I have not evaluated the order of magnitudes of the energies characteristic of cosmic ray phenomena. The voltages which would be required to speed up, by electric-field forces, the electrons to velocities corresponding to the given energies can serve as a measure of this magnitude. If one uses, as is customary, such a standard, then the mean energy of primary ray particles proves equal to approximately 10 billion electron-volts.

As for the total energy liberated in large atmospheric showers, it is a million or tens of millions times larger still than this mean energy of cosmic rays and is expressed in electron-volts by numbers equal to 10 raised to the sixteenth or even eighteenth power.

In consideration of the size of my report I am forced to resort in what follows to a still more synoptic style of presentation.

If considering as true the general concept of cosmic ray phenomena as expounded by me and if, in particular, it is true that protons possessing energies of the order of the energy of primary rays can very effectively cause electron-nuclear showers, then we should expect that in the upper layers of the stratosphere it is possible to observe the formation of composite electron-nuclear showers incomparably more often than at mountain altitudes.

This prediction was completely justified. A noteworthy apparatus was created by A. N. Charakhch'yan, co-worker in S. N. Vernov's group, which permits one to carry out in the stratosphere, hodoscopic observations which are transmitted to earth by radio signals. His hodoscopic devices are not so cumbersome and complicated as those used in mountains, but their principles of operation are the same.

As we saw, hodoscopic photographs permit immediate observation of what occurs in the various counters of the hodoscopic system. In the given case this also proves to be possible; here, the observer on the earth "sees" the picture of the phenomenon occurring in the atmosphere. Thus, something like television is realized. Such a comparison with television can be more valid in that some of the elements of television technology is present here. A fluorescing screen is photographed practically continuously on a moving photographic film; this screen being actually identical with those on which the image is obtained in television sets. The signal is recorded by a controllable spot formed by a narrow cathode-ray beam, which runs or scans horizontally the width of the film in 1/25 second, then returning very quickly to the initial position to repeat immediately its scanning run again. In this way a definite unfolding with time is realized on the screen. During this same time - the time of run (1/25 second) over the film's width by the cathode ray - a rapidly revolving motor, in the device, now high in the stratosphere, switches the sender of the transmitting apparatus from one counter of the hodoscopic system to another counter in rapid succession. Thus, in the course of this time (1/25 second) all counters of the hodoscope are examined successively. To each counter corresponds a definite place unfolding on the screen. If a given counter does not perform upon passage of a shower through a certain controlling system, on the screen a vertical pip is obtained at a definite place corresponding to the given counter. The counters that have operated are distinguished by the fact that such a pip is absent. If the controlling system has not operated, then a straight line is drawn without any pips and barographic signals are recorded. Each time that a shower selected by the controlling system has passed through the hodoscope this is observed in the dropping out of a certain number of pips; whereupon the entire picture of the shower is made apparent.

The apparatus described has permitted us to observe electron-nuclear showers caused by the primary cosmic ray particles in the stratosphere. Later this phenomenon has been successfully employed as a sort of indicator of the presence of primary particles at a given level in the stratosphere. Relative to the number of special showers observed per unit time, it proved possible to judge the magnitude of the flux, proportional to this number, of primary particles. In this way, S. N. Vernov and N. I. Dobrotin-Alekseev succeeded in finding how this flux becomes attenuated with penetration into the depths of the atmosphere. From observations at various latitudes by a method, whose description must be omitted here in order not to increase the size of my report, they obtained a fundamental result. They were the first to obtain the curve of absorption, in the atmosphere, of primary cosmic rays, and showed that this radiation is very rapidly absorbed in the atmosphere. The reason for the very rapid absorption is: the interaction of primary cosmic rays with nuclear matter and the catastrophic processes of an explosive nature connected with the transformation, in individual elementary acts, of colossal amounts of energy, which give rise to electron-nuclear showers. Figure 8 shows this absorption curve. It is not like the curve describing the behavior of total cosmic ray intensity in the atmosphere, about which I spoke in the beginning of my report.

This distinction is extremely characteristic. The curve shown earlier relates to a complicated complex of radiations generated by the primary agent. Here, how- ever, we have the absorption curve namely of the primary agent; that is, the primary cosmic rays.

In this scheme of cosmic ray phenomena, which I introduced in the beginning, it is now necessary after consideration of all these facts, to propose a new represent- ation, which looks like this:

Primary protons → electrons
→ mesons → cascade processes
nuclear-active particles

This rearrangement denotes an essential change in our presentations.

Essentially, as finally established now, the phenomena caused by primary cosmic rays and unfolding in the atmosphere originate in a nuclear process of an explosive nature, which we are now in a position to observe and investigate. It is an essen- tially new and already indisputably-established fact that such a nuclear explosive process results in the generation of intensive streams of high-energy electrons. Relying on this fact, we can now consider the basic scheme behind cosmic-ray phenomena as has been finally puzzled out. This fact together with others raises the ques- tion about some new mechanism governing the transformation of energy, as yet un- explained by theory.

One of the possible mechanisms which the theory is able to propose deserves particular attention. We have in mind the suggestion about the existence of new particles hitherto unobserved - namely, unusually unstable neutral mesons which decay with subsequent generation of photons. Recently this hypothesis received greater and greater affirmations. From observations which I discussed, it follows that if such neutral mesons also are formed in explosive showers along with charged mesons (which afterwards, in the second generation give rise to the electrons observed in the make-up of composite showers), then the life time of these neutral mesons cannot be greater than an insignificant part of a second, expressed by a fraction with numerator unity and denominator equal 10 to the tenth power.

In all probability, however, the life-time of such particles, if they exist, is still considerably less.

From the experimental material already available at the given stage of investigation of the problem we can draw many most interesting inferences concerning the conditions under which the collision of primary cosmic ray particles with atomic nuclei accompanies the explosive processes described. From the magnitude of the measured co-efficient of absorption of primary ray in air it follows, for example, that for sufficiently large energies practically each collision of a particle with nuclei of air atoms is accompanied by such explosive process. Moreover, there are reasons to believe that nuclear interaction of colliding particles is so intensive that the explosion occurs already in the surface layer of nucleons of this nucleus-target, into which the cosmic-ray particle colliding with it penetrates.

We cannot, of course, think that we are able even now or in the near future to establish some clear and detailed picture of what occurs and to obtain some accurate data about the nature of the phenomena and about the laws governing them. Even in a more detailed and deeper investigation I would be unable to report in this connection much more than what has already been stated by me. At this given stage this does not seem possible.

It would be completely erroneous, however, to infer from this that the exceptionally tense work and the great means spent to realize the investigations that I described are without reward. On the contrary, the results obtained surpassed all our expectations, in so as the discoveries made open new ways to fields still uninvestigated and to new heights of knowledge, the mastery of which finally leads to the reconstruction of our fundamental representations concerning the physical picture of the world.

I can state that Soviet physics is assured commanding positions and leading status on this advanced front of science as the result of the work described.

These results proved attainable because of the unusual conditions for developing investigations on an extraordinary scale, which conditions were created for us by the party and government, and because of this extensive support and assistance, which invariably allowed us a generous hand.

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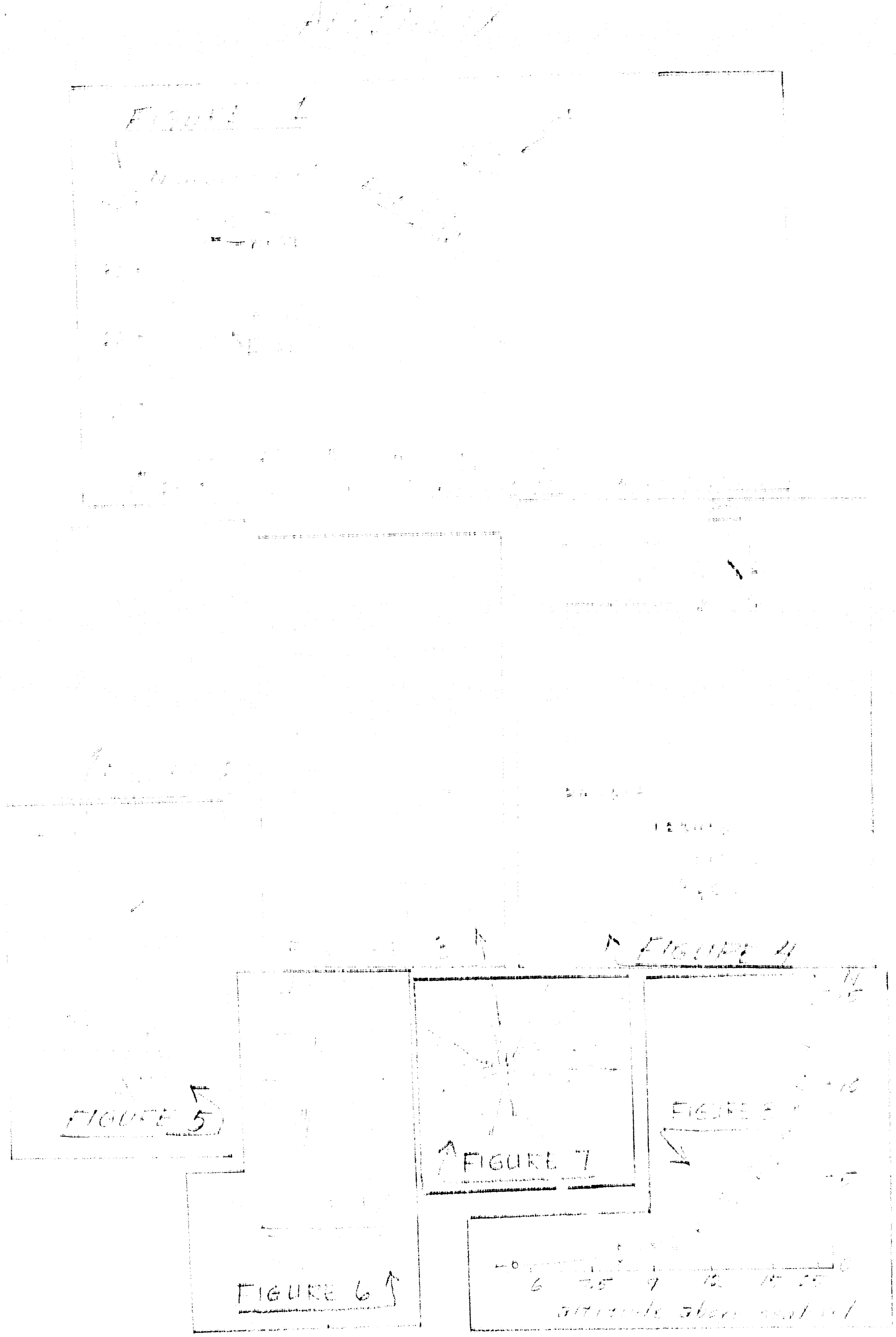


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